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Fahlbands of the Keret archipelago, White Sea: the composition of rocks and minerals, ore mineralization

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Abstract. This paper presents a complex mineralogical and geochemical characteristic (based on SEM-EDS, ICP-MS analysis) of the fahlband rocks of the Kiv-Guba-Kartesh occurrence within the White Sea mobile belt (WSMB). The term "fahlband" first appeared in the silver mines of Kongsberg in the 17th century. Now fahlbands are interlayers or lenses with sulfide impregnation, located in the host, usually metamorphic rock. The level of sulfide content in the rock exceed the typical accessory values, but at the same time be insufficient for massive ores. Fahlbands are weathered in a different way than the host rocks, so they are easily distinguished in outcrops due to their rusty-brown color. The studied rocks are amphibolites, differing from each other in garnet content and silicification degree. Ore mineralization is represented mainly by pyrrhotite and pyrite, and pyrrhotite grains are often replaced along the periphery by iron oxides and hydroxides, followed by pyrite overgrowth. At the same time, the rock contains practically unaltered pyrrhotite grains of irregular shape with fine exsolution structures composed of pentlandite, and individual pyrite grains with an increased Ni content (up to 5.4 wt.%). A relatively common mineral is chalcopyrite, which forms small grains, often trapped by pyrrhotite. We have also found single submicron sobolevskite and hedleyite grains. The REE composition of the fahlband rocks suggests that they are related to Archean metabasalts of the Seryakskaya and Loukhsko-Pisemskaya structures of the WSMB, rather than with metagabbroids and metaultrabasites common in the study area.

Key words: fahlbands; amphibolites; ore mineralization; rare earth elements

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Introduction. The term "*fahlbaands*" first came into use in the silver mines of Kongsberg (Northern Norway). Kongsberg was one of the main mining centers of Europe in the 17th-19th centuries, which mines were visited by many prominent geologists, (including foreign ones), and thanks to which the term spread throughout Northern Europe. The term was used for different ore types, now the generally accepted definition for this form of ore bodies is as follows: fahlbands are interlayers or lenses with sulfide impregnations, located in the host, usually metamorphic rock. Furthermore, the level of sulfide content in the rock should exceed the typical accessory values, but at the same time be insufficient for massive ores. In outcrops, weathered fahlbands are visible due to their rusty-brown color [11].

Sulfide-bearing rocks that build up beds and lenses are widespread in metamorphic complexes around the world. For example, zones containing sulfide impregnation are often found in rocks of the Precambrian age in Sweden. In this case, the areas suitable for ore mining are called fahlbands [11].

Such formations are also common in rocks of the Precambrian age in Finland. These so-called "black shales" are characterized by an increased content of graphite and iron sulfides, which prevail over chalcopyrite, sphalerite, or pentlandite [12]. Similar bands, fully repeating the structural pattern of the host rocks with coarse-grained sulfide impregnation, represented by pyrite, pyrrhotite, and subordinate quantity of graphite, are also observed in the Norwegian Caledonides [11].

Ore occurrences of this type were identified in the Karelian-Kola region. They are concentrated on the northern and southern coast of the Kandalaksha Bay of the White Sea. On the northern coast, in the area of Porya Bay (Medvezhy Island, Khedostrov, etc.), there are abandoned lead-silver

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mines that operated since the middle of the 16th century until the middle of the 18th century [9]. However, later attempts to revive silver mining in the region have been unsuccessful.

The area was studied by E.S.Fedorov, A.K.Boldyrev, D.S.Belyankin, V.A.Tokarev in the late 19th – early 20th centuries [8]. For the first time a detailed description and assessment of ore content, including gold, of the fahlbands on the southern coast of the Kandalaksha Bay, in the area of Kartesh Cape, were carried out by I.I.Ginzburg in 1921 [2]. In this region, detailed prospecting works were carried out by T.S.Levin in 1973 and N.N.Samorukov in 1985, which did not confirm the abnormally high gold contents in these ores [3]. In addition, the ore mineralization of the fahlbands was studied by V.A.Krupenik and his colleagues [3, 10]. Currently, the fahlbandas of the Kiv-Guba-Kartesh region are considered as potentially ore-bearing for precious metals. However, a detailed mineralogical and geochemical characteristic of rocks has not yet been completed, which determined the objectives of this study.

Geological setting The major part of the Chupino-Loukhskiy segment of the White Sea Mobile Belt (WSMB) is occupied by igneous and metamorphic formations, represented by rock complexes consisting of two subcomplexes: the Neoarchean Khetolambinskiy orthoamphibolite and Neoproterozoic Kotozerskyi migmatite-plagiogranite. The most promising in terms of noble metal mineralization is the Khetolambinskiy orthoamphibolite subcomplex [10].

A special role in the folded and disjunctive structure of the Khetolambinskiy subcomplex is played by flat-dipping faults – thrusts, feathering the main structure-forming fault of the northwest strike, forming permeable zones, and often controlling the placement of ore-bearing fahlbands [10]. There are two types of major structures within the Khetolambinskiy subcomplex: mafic zones with a length of several tens of kilometers and thickness of 2-6 km and areas of gneisses development (dome structures) parting these mafic zones. Mafic zones are composed mainly of amphibolites and crystalline schists of various compositions. Metaultrabasites bodies are often found among amphibolites [7]. Within the mafic zones, the fahlband horizons are interbedded with amphibolites and amphibole gneisses, forming members with a thickness of up to 80 m [3]. The associated magnetic anomaly is traced by an up to 80 m wide band along the coast to the North to the Kandalaksha Bay at a distance of up to 150 km. Fahlbands of the Kiv-Guba-Kartesh mineral occurrence form a 7 km long zone [4].

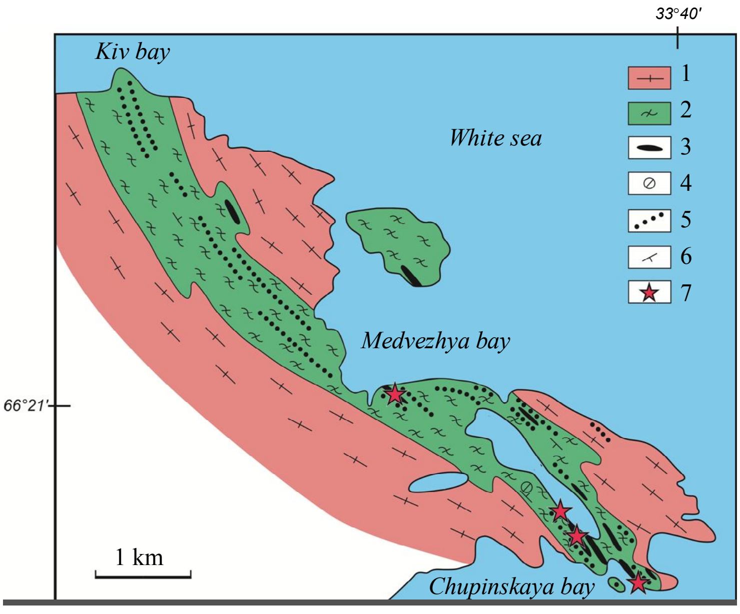

Fig. 1. Scheme of the geological structure of the Kiv-Guba-Kartesh mineral occurrence (according to Krupenik et al. [3], with amendments)

1 – biotite gneisses; 2 – amphibole gneisses, amphibolites; 3 – orthoamphibolites; 4 – pegmatites; 5 – fahlband horizons; 6 –elements of bedding; 7 – sampling points

This work presents the results of a mineralogical and geochemical study of five samples from the fahlbands collected during fieldwork on the White Sea coast near the Medvezhya Bay and Kartesh Cape (Fig.1). In the studied outcrops, the fahlbands deposited within amphibolites and form lenticular bodies of varying thickness (up to 5 m) with a visible length of up to 20 m. Fahlbands noticeably differ from the host rocks in their rusty-brown color and a more intense degree of weathering (Fig.2).

Methods. Analytical work was carried out on five key samples. The content of petrogenic (major) elements in the rocks was analyzed by the XRF method on an ARL 9800 OASIS X-ray spectrometer according to the standard technique (VSEGEI). The lower limit of the detection of major elements oxides is 0.01-0.05 %. Bulk analysis of rocks for rare and rare earth elements (REE) was carried out by the ICP-MS method on an ELAN-DRC-6100 quadrupole mass spectrometer according to the standard technique (VSEGEI). The relative error in elements detection does not exceed 5-10 %.

The chemical composition (Tables 1, 2), as well as minerals structure, were studied in flat-polished thin sections using BSE images obtained on two scanning electron microscopes CamScan MV2300 (VSEGEI) and JEOL JSM-6510 LA (IPGG RAS) equipped with JED-2200 energy dispersive spectrometer (JEOL). The analysis on JSM-6510 LA electron microscope (IPGG RAS) was performed under the following conditions: accelerating voltage 20 kV, 1 nA beam current, ZAF– correction. Standard samples of the composition were as follows: Si, Mg, Fe – olivine, Al – kaersutite, Ca – diopside, Na – jadeite, K – orthoclase, Mn – spessartine, Ti – TiO_2, as well as pure compounds and metals. The analytical spot size was 1-2 μm. The sums of the determined oxides and elements in the minerals analyzes are normalized to 100 %.

Fig.2. Fahlband outcrops

Results and discussion. *Mineral and petrographic characteristics*. All studied samples can be characterized as amphibolites, differing from each other in the amount of garnet and in the degree of silicification.

Garnet amphibolite (sample F1). The rock structure is determined by a significant amount of garnet porphyroblasts (about 50 % of the rock volume) and amphibole grains that are elongated and directed parallel to the schistosity planes (25 %). The size of garnet porphyroblasts ranges from 1 to 6 mm, they contain multiple inclusions of quartz, in some cases – ore minerals (pyrrhotite). According to its composition (see Table 1), garnet belongs to the grossular-almandine series (Alm 50-55 mol.%, Grs 27-29 mol.%, Prp 12-18 mol.%, Sps 2-4 mol.%).

The amphibole grains have a subidiomorphic habit and deep green tones of pleochroism. The chemical composition of amphiboles corresponds to Magnesio-hornblende [14]. In the intergranular space, fine-grained chlorite-sericite-plagioclase (up to An 88 mol.%) aggregates are observed. In one of these aggregates, a fine grain of gahnite, zinc spinel, was found. The rock also contains single grains of clinozoisite.

The amphibolite is extensively silicified; the quartz content is about 15 %. Besides, there is a large amount of ore mineralization (10 %), but it is highly oxidized and difficult to diagnose by optical methods (it is described in detail below). The orientation of the ore minerals coincides with the general schistosity of the amphibolite.

Table 1

Representative composition analyzes of the main rock-forming minerals of the fahlband rocks (based on SEM-EDS results)

Components	Garnets			Amphiboles				Plagioclases				Clinozoisite	Epidote	
Sample	F1		F2	F1	F2	F4	F5	F1	F2	F4	F5	F1	F5	
Point number	004	008	016	007	014	007	003	010	015	028	007	027	004	006
SiO_2	37.32	38.30	37.50	46.61	48.15	44.62	41.25	45.08	47.10	60.18	60.76	39.97	38.94	39.45
TiO_2	–	–	–	0.67	0.62	0.94	1.17	–	–	–	–	–	–	–
Al_2O_3	21.72	22.01	21.65	12.60	10.37	13.00	14.19	35.17	34.77	24.76	24.44	33.77	26.46	26.57
Cr_2O_3	–	–	–	0.05	–	–	–	–	–	–	–	–	–	–
$Fe_2O_3^*$	26.12	23.91	24.9	14.06	13.44	14.26	18.93	–	–	0.72	–	–	–	9.57
MnO	1.80	0.76	1.50	0.10	0.18	0.35	0.62	–	–	–	–	–	–	0.04
MgO	2.93	4.66	4.60	11.59	12.38	11.97	6.98	–	–	–	–	–	–	–
CaO	10.12	10.32	9.83	12.36	12.32	12.32	12.13	17.41	17.16	6.27	7.70	25.14	24.46	24.37
Na_2O	–	–	–	0.87	0.78	1.18	1.44	1.08	1.74	7.97	7.04	–	–	–
K_2O	–	–	–	0.18	0.30	1.12	1.03	0.46	–	–	–	–	–	–
ZnO	–	–	–	–	–	–	–	–	–	–	–	–	–	–
The amount	100.01	99.96	99.98	99.09	98.54	100.01	98.02	99.20	100.77	100.00	100.00	100.00	100.00	100.00
	Crystal-chemical coefficients													
Si	2.94	2.98	2.93	6.70	6.95	6.43	6.26	2.09	2.14	2.38	2.72	2.97	2.95	3.01
Ti	–	–	–	0.07	0.07	0.10	0.13	–	–	–	–	–	–	–
Al	2.02	2.02	1.99	2.13	1.76	2.21	2.54	1.92	1.87	1.30	1.29	2.96	2.41	2.39
Cr	–	–	–	0.01	–	–	–	–	–	–	–	–	–	–
Fe^*	1.62	1.53	1.47	1.50	1.57	1.35	2.12	–	–	0.03	–	0.07	0.64	0.61
Mn	0.12	0.05	0.10	0.01	0.02	0.04	0.08	–	–	–	–	–	–	–
Mg	0.34	0.54	0.54	2.48	2.66	2.57	1.58	–	–	–	–	0.01	–	–
Ca	0.85	0.86	0.82	1.90	1.91	1.90	1.97	0.86	0.84	0.30	0.37	2.00	1.97	1.99
Na	–	–	–	0.24	0.22	0.33	0.42	0.10	0.15	69.00	0.61	–	–	–
K	–	–	–	0.03	0.06	0.21	0.20	0.03	–	0.01	–	–	–	–
Zn	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 2

Representative composition analyzes of ore minerals in fahlband rocks (based on SEM-EDS results)

Components	Pyrite			Chalcopyrite			Pyrrhotite		Pentlandite	Sobolevskite	Hedleyite
Sample	F4	F1		F1	F2	F4	F1	F4	F1	krt 10	krt 9
Point number	2	2	32	20	4	25	18	13	23		
Fe	47.09	44.40	41.02	31.30	30.73	30.86	61.43	59.95	30.11	6.69	–
Ni	0.72	2.12	5.39	–	–	–	0.05	0.28	33.53	–	–
S	52.2	53.48	53.38	34.71	34.30	34.41	38.52	39.77	33.19	–	–
Cu	–	–	–	33.99	34.97	34.73	–	–	–	–	–
Co	–	–	–	–	–	–	–	–	2.77	–	–
Pd	–	–	–	–	–	–	–	–	–	33.25	–
Bi	–	–	–	–	–	–	–	–	–	60.06	81.32
Te	–	–	–	–	–	–	–	–	–	–	18.68
The amount	100.01	100.00	99.79	100.00	100.00	100.00	100.00	100.00	99.60	100.00	100.00
	Crystal-chemical coefficients										
Fe	1.02	0.95	0.88	1.03	1.01	1.02	0.96	0.93	4.18	0.83	7.97
Ni	0.01	0.04	0.11	–	–	–	0.00	0.00	4.43	–	–
S	1.97	2.00	2.00	1.99	1.97	1.98	1.04	1.07	8.03	–	–
Cu	–	–	–	0.98	1.01	1.01	–	–	–	–	–
Co	–	–	–	–	–	–	–	–	0.46	–	–
Pd	–	–	–	–	–	–	–	–	–	2.17	–
Bi	–	–	–	–	–	–	–	–	–	2.00	3.00
Te	–	–	–	–	–	–	–	–	–	–	–

Garnet-bearing amphibolite (sample № F2, F3, F4, F5). This variety of rocks is in many ways similar to the previous one, but differs in a much lower content of garnet (single grains), varying degree of silicification (from its absence to almost complete replacement of other rock-forming minerals by quartz). Since there is no direct correlation between the silicification degree and ore minerals content, it is assumed that in this case silicification is superimposed and does not associate with ore formation.

The directional texture of the rock is not so strongly expressed and can be revealed mainly due to the presence of elongated amphibole grains. As in garnet amphibolites, in this case, amphiboles have a subidiomorphic habit, are brightly colored, and their composition is similar to the composition of the above-described amphiboles. There is a significant amount of secondary minerals (limonite, etc.) developing on ore minerals.

Single garnet grains form small porphyroblasts (up to 0.5 mm in diameter), practically free of inclusions. Plagioclases in these amphibolites can be divided into two types: the plagioclases of basic composition (An 70-84 mol.%), forming relatively large hypidiomorphic grains (up to 0.5 mm), and plagioclases of intermediate composition (An 30-40 mol.%) which overgrow or replace the first one. Accessory minerals are epidote, zircon, titanite, and rutile. In some cases (sample F5) epidote is represented by small single grains or (sample F4) forms quartz-epidote intergrowths (Fig.3, *a*).

The limited analytical data and a significant degree of fahlband rocks alteration allow only an approximate estimation of the P-T parameters of the metamorphic parageneses formation. The low-Mg garnet (Prp 12-18 mol.%), along with the high-Mg amphibole, make it possible to assume the metamorphism temperature value does not exceed 650 °C. The presence of high-Ca plagioclase (An up to 84 mol.%) together with rutile, ilmenite, quartz, and garnet limits the pressure by the values of 6-8 kbar. These parameters suggest that the garnet-amphibole-plagioclase paragenesis was formed under conditions not higher than the moderate-pressure amphibolite facies.

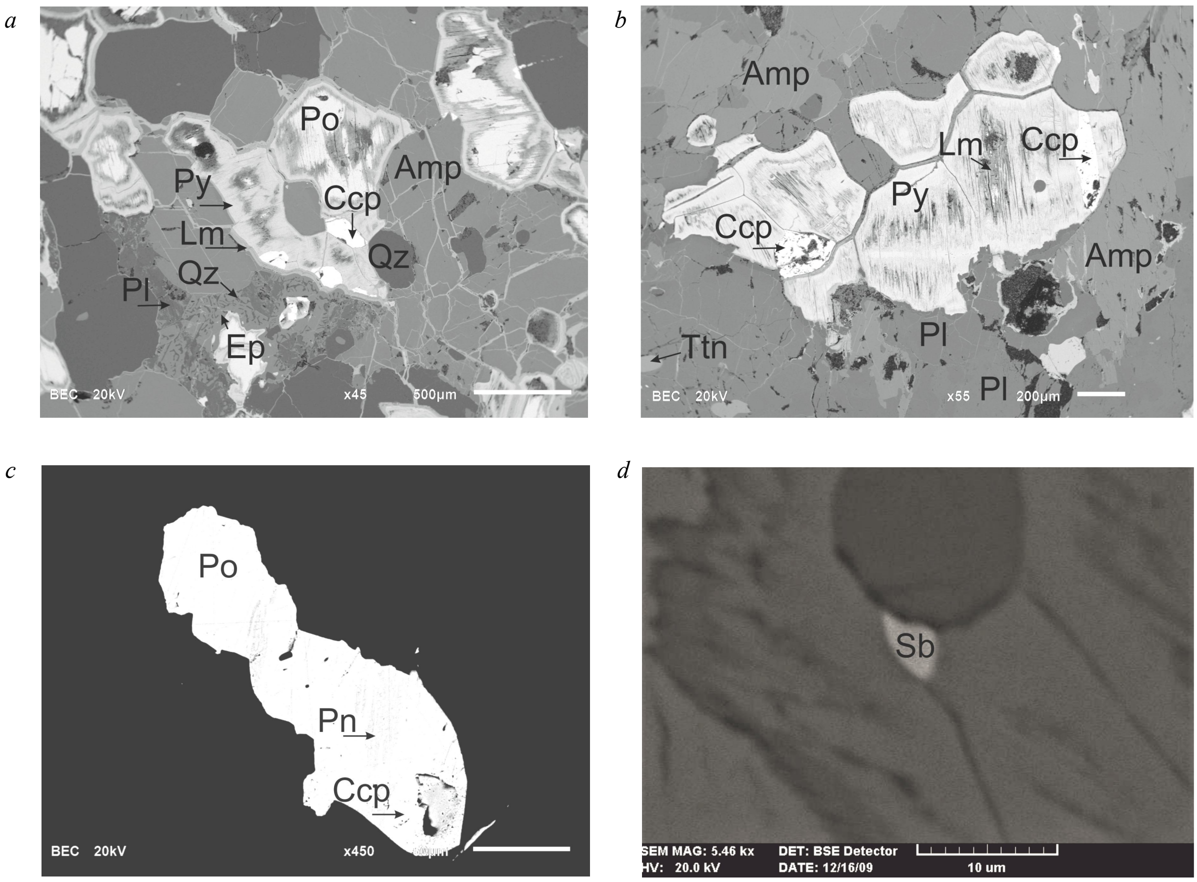

Fig.3. BSE images of ore minerals from the fahlband rocks
Sb – sobolevskite, other mineral abbreviations are given according to Whitney and Evans [15]

Ore mineralization is represented by a rather poor set of minerals. The most common phases are pyrrhotite and pyrite. Pyrrhotite grains are often replaced along the periphery by iron oxides and hydroxides, followed by pyrite overgrowth (Fig.3, *a*, *b*). The size of such pyrrhotite-pyrite aggregates (samples F2, F4) ranges from 100 to 500 μm. These features may indicate two diverse geological events (or one prolonged), which resulted in the sulfide mineralization in the studied rocks.

In some cases (sample F1) there are practically unaltered pyrrhotite grains of an irregular shape with fine exsolution structures (Fig.3, *c*), composed of pentlandite and the similar individual pyrite grains with an increased Ni content (up to 5.4 wt.%).

In addition to the minerals described above, chalcopyrite is also common, forming elongated grains from 20 to 100 μm across. Its relationship with other ore minerals is not so clear, although in some cases there are small chalcopyrite grains trapped by pyrrhotite (sample F1). We have also found single submicron sobolevskite and hedleyite grains (Fig.3, *d*)

Geochemical features of rocks. To discuss the geochemical features of the fahlbands, we used data (both author's and published) on the composition of similar rocks of the WSMB. The comparison was based on several groups of rocks (Table 3): metabasites (metaleucogabbro) of presumably Archean age (samples 609 and 616); a group of basic rocks of Proterozoic age – eclogitized to varying degrees (samples S1, S3, V1) [1] or practically unaltered (samples 300, 309, 310) metagabbroids; a group of metaultrabasites– olivine-pyroxene-bearing metaporphyrites, metaperidotites (samples 405-444, B1326a, B1326b). Also, we used the analysis results of the Archean metabasalts of the Seryakskaya and Loukhsko-Pisemskaya structures (sample S-2650-2, S-2800-16, E-7/1, E-144-4) [6].

Table 3

Major (wt%) and rare (ppm) elements in rocks composition

Components	Falhband rocks					Metabasites								Metaultrabasites			
	F1	F3	F2	F4	F5	616	609	S1	S3	V1	300	309	310	405	410	444	B1326b
SiO_2	49.83	65.45	39.39	33.61	52.57	51.47	49.68	49.45	49.37	49.62	52.70	53.30	52.80	48.18	50.81	48.15	45.77
Al_2O_3	17.24	9.72	10.27	3.90	14.68	10.27	12.21	14.27	13.60	13.73	13.30	12.00	9.16	9.50	12.78	7.44	7.88
TiO_2	1.14	0.39	0.06	0.42	1.22	1.00	2.13	2.04	2.01	2.08	1.00	1.24	0.35	0.56	0.66	0.46	0.37
Fe2O3*	16.78	10.01	36.06	40.57	13.13	11.98	17.58	16.29	16.38	16.49	13.30	12.30	10.35	10.80	10.98	12.27	11.77
MnO	0.48	0.05	0.50	0.12	0.30	0.16	0.25	0.17	0.24	0.24	0.21	0.21	0.14	0.16	0.18	0.18	0.21
MgO	4.33	2.88	3.40	4.04	3.92	12.72	6.20	5.57	5.67	5.45	6.07	7.22	15.60	18.92	12.16	23.94	19.19
CaO	9.01	5.79	3.14	3.99	8.87	8.86	9.36	10.78	9.65	9.45	10.30	10.20	9.27	8.51	9.40	5.32	9.17
Na_2O	0.47	0.90	0.22	0.54	2.40	0.73	1.88	1.05	2.32	2.17	2.06	2.21	1.53	1.48	1.91	1.02	0.68
K_2O	0.39	0.21	0.02	0.27	0.65	1.67	0.82	0.33	0.75	0.68	0.45	0.41	0.56	0.21	0.64	0.40	2.76
P_2O_5	<0.05	0.08	<0.05	<0.05	0.11	0.06	0.20	0.18	0.17	0.19	0.10	0.11	0.08	0.08	0.08	0.07	<0.05
LOI	0.61	4.78	7.45	12.70	2.22	1.04	<0.1	0.26	<0.1	0.11	0.75	1.60	1.12	1.27	0.45	0.36	1.72
Mg#	0.21	0.22	0.09	0.09	0.23	0.51	0.26	0.25	0.26	0.25	0.31	0.37	0.60	0.64	0.53	0.66	0.62
The amount	100.00	100.00	101.00	100.00	100.00	99.97	100.00	100.00	100.00	100.00	100.39	100.84	101.08	99.68	100.00	99.59	99.53
V	311	112	35.2	95.3	128	222	337	287	289	288	567	291	158	156	194	138	162
Cr	251	55.9	40.7	423	267	1220	237	141	157	126	819	115	798	1880	881	2480	2460
Co	40.8	40.9	171	177	17.5	n.d.	n.d.	43.9	45.0	45.3	46.4	55.4	63.4	75.3	63.0	90.0	92.0
Ni	112	42.6	131	1020	105	n.d.	n.d.	72.4	64.5	66.3	57.0	66.6	374	524	198	706	827
Cu	86.1	439	53.3	773	14.1	n.d.	n.d.	142	57.9	130	113	252	32.9	7.36	59.6	19.3	16.8
Zn	497	103	169	63.4	81.3	n.d.	n.d.	77.3	98.6	109	96.7	80.0	71.3	54.3	68.5	79.5	82.4
Ga	19.5	13.4	7.97	4.63	10.9	17.1	19.2	16.1	17.7	17.5	15.7	15.9	10.3	11.5	13.3	9.39	8.53
Ge	3.04	1.27	2.64	0.56	0.55	n.d.	n.d.	1.63	1.46	1.33	1.83	1.02	1.50	1.36	1.43	1.22	1.69
Rb	26.3	11.8	<2	2.93	7.34	69.9	25.5	8.24	23.2	22.3	6.89	5.3	10.6	3.73	15.0	9.88	131
Sr	112	56.8	2.81	13.3	119	31.7	157	295	134	119	88.6	116	158	85.4	173	104	19.4
Y	24.8	11.7	8.02	8.93	14.3	13.2	34.0	30.0	30.0	31.4	21.1	21.4	10.3	11.8	14.1	8.51	7.36
Zr	49.0	93.0	34.5	22.5	62.1	67.3	138	115	122	116	64.4	77.9	46.2	56.3	58.4	42.3	15.9
Nb	3.69	4.40	<0.5	1.02	4.25	3.80	10.5	10.4	9.97	7.91	4.62	5.81	1.58	3.24	2.65	1.88	1.09
Mo	0.74	1.96	4.37	3.24	<0.6	0.64	1.48	0.87	0.78	<0.6	0.62	0.69	<0.6	1.26	<0.6	0.62	<0.6
Sn	4.87	1.35	1.40	1.27	0.65	1.12	1.91	1.18	1.32	7.07	0.88	0.91	0.57	0.63	0.62	0.49	0.70

End of Table 3

Compo-nents	Falhband rocks					Metabasites								Metaultrabasites			
	F1	F3	F2	F4	F5	616	609	S1	S3	V1	300	309	310	405	410	444	B1326b
Cs	4.28	1.00	0.21	<0.1	0.61	2.55	0.72	<0.1	0.51	0.82	0.26	0.18	0.37	0.42	0.37	0.49	9.48
Ba	92.7	68.4	8.44	12.2	87.7	263	243	40.6	218	195	96.3	68.8	139	39.0	203	145	334
La	3.96	3.28	1.16	3.00	4.7	5.96	18.4	16.3	14.1	12.5	5.47	7.39	6.78	8.47	8.59	6.44	2.40
Ce	9.85	7.92	2.93	6.77	10.0	14.4	37.5	36.0	32.8	30.0	13.2	16.2	14.6	20.2	19.0	14.2	5.12
Pr	1.54	1.12	0.39	0.93	1.35	2.23	5.36	4.65	4.47	4.16	1.91	2.41	1.87	2.55	2.43	1.76	0.76
Nd	8.01	4.88	1.68	4.54	6.24	10.1	23.7	20.7	19.2	18.2	8.90	11.9	8.87	11.0	10.8	7.58	3.09
Sm	2.61	1.21	0.69	1.21	1.80	2.63	5.82	4.85	4.64	4.77	2.51	2.81	1.71	2.31	2.39	1.65	1.00
Eu	1.08	0.67	0.43	0.40	0.60	0.80	1.44	1.43	1.41	1.37	0.99	1.03	0.60	0.69	0.75	0.47	0.29
Gd	3.52	1.64	1.06	1.51	2.08	2.45	5.39	5.51	5.39	5.60	3.08	3.07	1.67	2.12	2.22	1.51	0.98
Tb	0.63	0.28	0.19	0.24	0.4	0.43	0.97	0.87	0.87	0.92	0.53	0.52	0.28	0.38	0.42	0.25	0.19
Dy	4.10	1.85	1.39	1.56	2.43	2.58	5.94	5.16	5.45	5.61	3.68	3.49	1.41	2.07	2.45	1.58	1.17
Ho	0.90	0.39	0.28	0.30	0.52	0.55	1.25	1.11	1.09	1.16	0.85	0.80	0.35	0.44	0.51	0.31	0.27
Er	2.55	1.29	0.95	0.84	1.58	1.37	3.81	3.26	3.35	3.46	2.41	2.04	0.92	1.30	1.47	0.93	0.80
Tm	0.38	0.23	0.15	0.13	0.24	0.17	0.52	0.46	0.47	0.47	0.38	0.35	0.17	0.18	0.21	0.13	0.13
Yb	2.44	1.48	0.91	0.85	1.44	1.08	3.45	2.89	3.03	3.05	2.27	2.26	1.06	1.37	1.51	0.82	0.85
Lu	0.37	0.25	0.16	0.10	0.21	0.17	0.53	0.45	0.47	0.43	0.34	0.32	0.15	0.19	0.20	0.12	0.10
Hf	1.69	2.74	1.08	0.57	1.56	1.83	3.84	3.23	3.34	3.19	1.68	2.30	1.44	1.54	1.56	1.20	0.65
Ta	0.23	0.61	0.11	<0.1	0.34	0.32	0.70	0.85	0.96	0.98	0.30	0.38	0.12	0.16	0.17	0.12	<0.1
W	1.00	0.94	0.71	<0.5	<0.5	1.26	<0.5	<0.5	0.56	<0.5	<0.5	<0.5	<0.5	2.37	<0.5	<0.5	<0.5
Pb	12.0	7.87	1.65	1.90	3.05	n.d.	n.d.	3.34	1.92	1.19	2.07	1.83	2.70	2.84	7.91	6.00	4.67

Note. Explanations to table.3 can be found in the text. Mg# = MgO / (MgO + $Fe_2O_3^*$) [4].

When considering the composition of the fahlband rocks, it is quite doubtful to use the standard petrochemical characteristics describing the basicity of the rocks, due to the significant degree of superimposed processes (silicification) that strongly deoxidize the rock. As a result, the silica content in these rocks significantly varies from 33 to 65 wt.%, (Table 3). However, some patterns in the content of the major elements deserve attention. First, the MgO content in the fahlband rocks is significantly lower than in ultramafic and some mafic rocks (Table 3). In terms of magnesia content, fahlbands are closer to basic rocks [5]. Second, in some cases (samples F2 and F4), the $Fe_2O_3^*$ content strongly increases (up to 40 wt.%), which correlates with significant ore mineralization in these samples.

In general, compared with the other rock types, the fahlband rocks are enriched in several metals (Cu, Co, Mo) (Fig.4, *a*, *b*), which is consistent with the presence of ore minerals, containing these elements. A negative correlation between Cu and Cr may indicate that copper mineralization is not associated with ultramafic magmatism. In some cases (sample F2, F4), the fahlband rocks are depleted in such lithophile elements as Rb, Ba, Nb, and Sr.

The REE spectra of the fahlband rocks are poorly differentiated (Fig.4, *c*) with their relatively low total REE content, varying from 12 to 45 ppm (Table 3). In some cases (sample F2, F3), we observe a pronounced positive Eu anomaly (Eu / Eu* averages 1.5), which is probably associated with an increased amount of plagioclase in these rocks. The REE spectra in the composition of metagabbroids and metaultrabasites are much more differentiated (Fig.4, *d*, *e*); in addition, the total content of REE in metagabbroids is higher and ranges from 40 to 114 ppm (Table 3). However, the total content and form of REE spectra in the composition of the fahlbands rocks and metabasalts of the Seryakskaya and Loukhsko-Pisemskaya structures are quite similar [6]. This suggests a genetic relation between the fahlbands and metabasalts of the above structures, rather than with the metagabbroids and metaultrabasites common in the study area.

Conclusions. The authors were the first to carry out a comprehensive mineralogical and geochemical characteristic (based on SEM-EDS, ICP-MS analysis) of the fahlband rocks of the Kiv-Guba-Kartesh occurrence within the White Sea mobile belt (WSMB). Fahlband rocks can be characterized as amphibolites, differing from each other in garnet content and silicification degree. Ore mineralization is represented by a rather small set of minerals. The most common phases are pyrrhotite and pyrite. Pyrrhotite grains are often replaced along the periphery by iron oxides and hydroxides, followed by pyrite overgrowth. In some cases, there are barely altered pyrrhotite grains of an irregular shape with fine exsolution structures composed of pentlandite, and individual pyrite grains with an increased Ni content (up to 5.4 wt.%). We have found single submicron sobolevskite and hedleyite grains. The REE distribution in the composition of fahlband rocks suggests that they are related to Archean metabasalts of the Seryakskaya and Loukhsko–Pisemskaya structures of the WSMB, rather than with metagabbroids and metaultrabasites common in the study area.

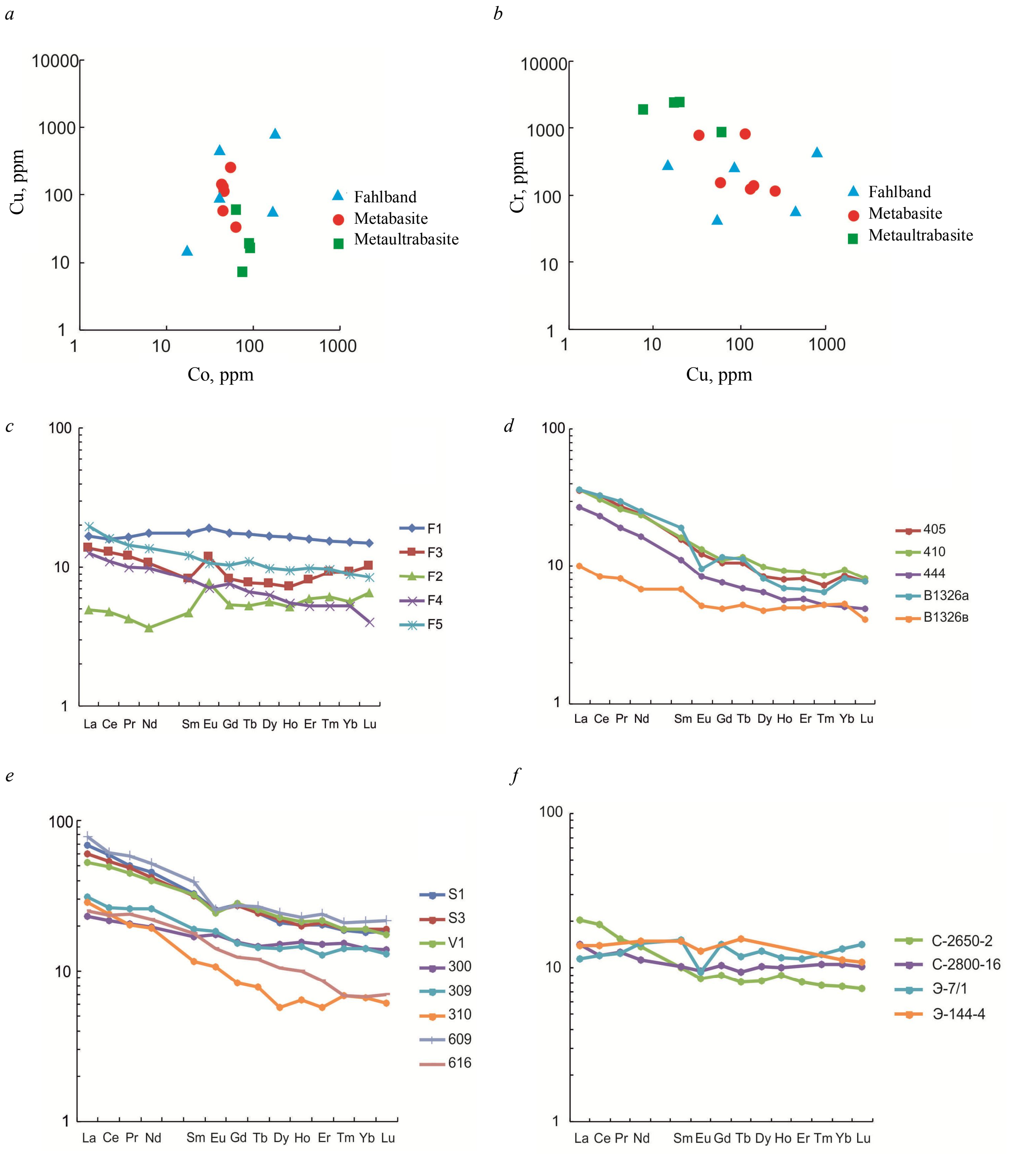

Fig.4. Binary plots for fahlband rocks, metabasites (metagabbroids and metabasalts), and metaultrabasites (*a*, *b*)
The REE spectra for the fahlband (*c*) rocks, (*d*) metaultrabasites, (*e*) metagabbroids, and metabasalts according to A.I.Slabunov [6] (*f*).
The REE content is normalized to the CI chondrite composition according to McDonough and Sun [13]

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